E.02.21-D08/M015-SAFECORAM-Final Project Report

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Abstract

The present document represents the final report of the WP-E SAFECORAM project. In accordance with template for the Final Report of WP_E projects, the information contained in the document summarise the technical contents and results of the project, provide a complete overview of all deliverables, provide a complete overview of all dissemination activities, describe exploitation possibilities, analyse the lessons learnt at project level, provide a complete analysis of use of resources.

Authoring & Approval

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Intellectual Property Rights (foreground)

Not applicable.

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Publishable Summary

Overview of SAFECORAM (Sharing of Authority in Failure/Emergency Condition for Resilience of Air Traffic Management)

The project proposed, structured and implemented a possible global approach to improve the resilience of the ATM system, as it can be depicted for the long term future, from the year 2050 and beyond. To develop and analyse the approach, a number of relevant ATM scenarios have been proposed, and possible failure conditions arising in those scenarios considered. Failure conditions normally produces a reduction in the global system performances. A resilience metric, which lies on the ATM system performance evaluation, expressed as a function of a set of KPIs in relevant Key Performance Areas of the SESAR Performance Framework, has been developed. Based on recent published tasks allocation methods and on the resilience metric adopted, a quantified task allocation approach has been delineated, supporting the sharing of tasks allocation and authorities between system agents, humans or machines. An original methodology has been developed, implemented and applied to the project scenarios in a way that allow to identify the allocation of residual resources of the system which optimizes the system resilience. A dynamic simulator of the ATM system, which implements several different ATM system actors, both humans and machines components, actors has been developed, and a simulation campaign has been carried out in order to verify the methodological approach validity.

The research project is a preliminary study to provide a structured global approach to measure and to optimize the ATM system resilience, by reallocating functions and authorities. Detailed studies and analyses will be required to provide sound results to a number of issues which in the current project have been dealt with as hypotheses and assumptions.

Project motivation

The ATM system is rapidly growing in complexity, due to a number of factors, ranging from the increasing traffic level to a more strict interconnections among world areas, as well as to the increasing typology of airspace users. In fact, this is an ever increasing need when one take into consideration the growing request for the integration of Remotely piloted/Unmanned aircrafts in the managed airspace system and the expected diffusion of the personal air transport system that will integrate the current categories of transportation aircrafts.

Furthermore, the automation level in the air traffic management system is continuously increasing and totally autonomous flights are the final goal of such clear tendency in the aviation transportation system. Notwithstanding, for the foreseeable future, it is foreseen that human will continue to play a central role in ATM system, and it is widely stated that human will remain the final resource for directly take the control in emergency conditions.

Actually, non-nominal, abnormal and emergency conditions can vary widely both in type and measure of system performance degradation and, depending on that, also delegation of automated control functions to systems or humans can be different. The capability of identify what is the best way to share control authority between systems and humans remain, as of today, one of the main relevant topic for which solutions have to be developed in view of a resilient air transportation system targeting high level of automation in ATM.

All those complexity factors can also affect the ATM system “fragility”, interpreted as a growing possibility of the ATM system performance drop in presence of failures, emergencies, unexpected events. Resilience is consequently becoming the focus in many research studies on the future ATM system.

Approach outline

Resilience Engineering in ATM is a topic as relevant as recent, in the today research activities and scientific literature. In fact, a relevant amount of recent efforts has been and is currently committed to the identification of a commonly agreed definition of Resilience in ATM and to the engineering approach of such a concept. The EUROCONTROL definition for Resilience in ATM, as “the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions”, has been finally widely accepted as a proper understanding of resilience applicable to the ATM system.

While a convergence to a common understanding of the resilience in ATM is maturing, there is still room for proposing original approaches to the resilience engineering problem.

In SAFECORAM project, the resilience engineering problem is expressed in terms of global ATM system performance loss, where the performance of the ATM system is expressed by the way defined in the SESAR Performance Framework, thus related to its KPAs and expressed quantitatively in terms of the corresponding KPIs. The approach originally proposed in SAFECORAM considers dealing with the resilience engineering problem by minimizing the ATM system performance loss under disturbances through an optimal task re-allocation between humans and systems which grants the minimum loss of performances of the ATM system also in non-nominal conditions.

The whole SAFECORAM proposed approach has been articulated in the following steps:

a. Develop a Resilience Engineering for ATM operative definition;
b. Propose a quantitative metric for resilience, based on the use of KPIs of the SESAR Performance Framework;
c. Develop a quantified Functional Task Allocation Method which allows to associate a value of the selected KPIs for each different task allocation;
d. Build a tool to transform the task allocation tables in a graph so to allow the application of an optimization method to the resilience engineering problem;
e. Develop a method for optimal search on a complex graph;
f. Apply the method to the proposed scenarios;
g. Verify the feasibility of the optimal task allocation and validate the proposed methodology through the dynamic simulation of the proposed scenarios in nominal and non-nominal conditions.

Key results and conclusions

The whole approach to Resilience Engineering of the ATM as an optimal task allocation problem has been finalized in the project. No inconsistencies have been found in the proposed approach, as emerge from the application of the approach to several scenarios, which have been used as study cases in the project.

By making reference to the steps listed in the previous paragraph, some detail about project results is provided in the following.

The conceptual synthesis of the way the project dealt with ***steps a.*** **and** ***b.*** is expressed by means of Figure 1.

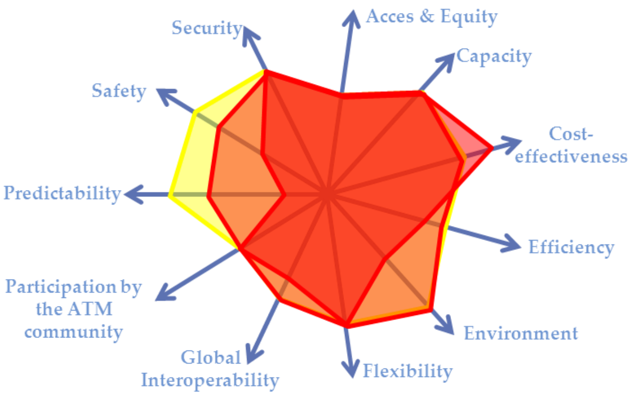

Figure 1-The ATM system performance global measure

SAFECORAM project expresses the resilience as the level of the ATM system residual global performance, as resulting from tasks and authority reallocation consequent to a failure/hazard which prevent the full availability of its resources. In Figure 1, the yellow area represents the nominal ATM system performance for a certain scenario under analysis. Once failure occurs, for each different mitigation action, different values of the indicators (KPIs) characterizing the SESAR performance areas (KPAs) will be associated to each new system status (which in turn corresponds to the system use of resources), consequently resulting in a different residual global performance of the system, as represented by the (two) red areas in the figure.

The full SESAR Performance Framework will be completely defined by a set of twelve Areas, the eleven areas defined by ICAO for the identification of the ATM system status, and the Human Performance (not explicitly included in the ICAO model).

Because at the date, four KPIs in the SESAR Performance Framework have a clear quantitative definition, we taken these four indicators in the SAFECORAM project, which specifically are the Fuel Burn, the Delay, the Pollution and the Capacity.

In Figure 2 the loss of performance between nominal condition and a (just as an example) degraded ATM system condition under failure is expressed as the areas difference, depicted in grey.

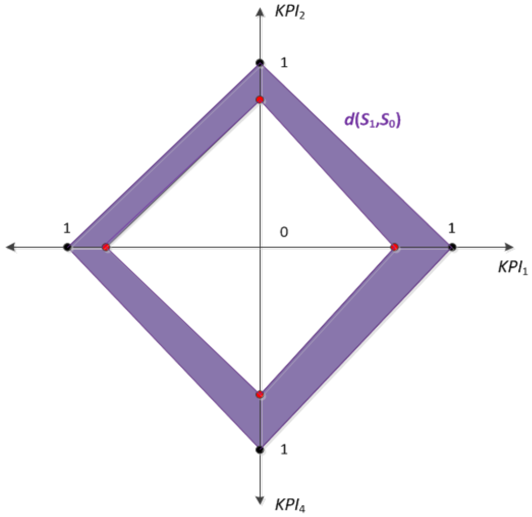

Figure 2-Performance loss as difference of the state areas.

Once a “disturbance” (an abrupt event, either expected or unexpected) occurs, usually a huge number of alternatives for the ATM system functions allocation among the residual available resources (human or automation, in the interpretation of the problem as an authority sharing approach) exists. The definition of a suitable methodology is consequently required to select, among the several alternatives functions allocation, the optimal one, which assure the maximum system residual performance level.

Before to start with the analysis of the best methodology to apply, the project solutions to ***steps c.* and *d.*** are considered in the following.

After the triggering of a disturbance on the system, that is after the ATM system is pushed in a non-nominal condition which threatens its nominal operations and performance, the proposed approach expects that the affected tasks can be reallocated, involving still available humans and systems. If a runway of an airport must be closed, arriving aircrafts can be required to use different runways, or can be diverted on neighbor airports, or any combination of these solutions can be implemented. In order to identify all these possible alternatives, a Task Allocation method is required. Starting from applicable proposed methods in reference literature [FRAM (Functional Resonance Analysis Method), RAG (Resilience Analysis Grid), CWA (Cognitive Work Analysis) and WDA (Work Domain Analysis)], in SAFECORAM the basic function task allocation has been integrated with a quantitative approach for task execution performance measurement. The proposed measures for the tasks allocation makes still reference to KPIs of the SESAR framework, for its quantitative contents. At the date, because the SESAR performance framework is still to be completed, a peculiar way to build a quantitative measure has been structured, by using the Operational Improvements measures of the SESAR program. It is expected that the full completion of the SESAR performance framework will overcome current hypotheses and some degree of arbitrary in the composition of the model.

Because relevance to quantitative components is not common in task allocation methods, a further result of the project is, therefore, a method which proposes a quantitative value for performance indicators to the tasks allocation, and a way to evaluate the performance degradation of tasks execution when it differs from the nominal condition.

Twelve scenarios have been developed to verify the consistency of the proposed approach. The following Table 1 just lists the scenarios identification labels.

Scenario n.	Description
1	FMS partial failure during approach and landing
2	Unexpected thunderstorm over airport in presence of mixed traffic (conventional, RPAS, PATS)
3	Uplink loss during en-route phase
4	Taxiway incursion during take-off taxiing
5	Pressurization system failure during en-route phase
6	ASAS activation during en-route phase of commercial vehicles
7	Big airport closure due to snow
8	Activation of a temporary segregated area due to natural disaster
9	GNSS failure over a wide area
10	PATS Remote Pilot Station communication link loss
11	Datalink disturbance for general aviation aircraft
12	Uncontrolled RPAS fully automatic vehicle

Table 1 Project Scenarios identification

Each scenario is characterized by its nominal execution, unless a triggering event (an emergency or an unexpected condition) requires a totally new arrangement of the system. Normally, there are several alternative arrangements, which can all assure that the ATM system can continue to provide its services.

IN SAFECORAM, given a scenario, the set of its alternative flows can be modelled as a weighted DAG (Directed Acyclic Graph).

The DAG is named flow graph or resilience DAG. The flow graph concept allows to map the resilience management problem in the problem of finding the path that exhibits the minimum value for the SAFECORAM resilience metric. Given a flow distance function, we define the resilience management problem as an optimization problem, that is the problem to find the best alternative flow in the scenario that has the minimum value of the SAFECORAM resilience metric with respect to the nominal flow. This problem resembles the shortest path problem in graph theory, which aims to find a path between two nodes in a weighted graph such that the sum of the weights of its constituent edges is minimized. The main difference with the shortest path problem is that we are interested in minimizing a function of the weight of the edges and not simply the sum of the weights of the edges. In other words, the SAFECORAM resilience management problem may be considered as a more general formulation of the shortest path problem.

The resilience metric may be one of the functions described by Figure 1 and Figure 2. A suitable coefficient may be assigned to each KPI in order to set the importance of the KPI with respect to the others. Three sets of coefficients have been defined in the project, with the contribution of the operational experts involved, and they roughly correspond to three ATM stakeholders point of view: General, Airline and Airport (Table 1). The definitions of three stakeholders profiles aims to demonstrate the flexibility in the customization of the metric function, so that some aspects in the optimization process can be considered more important of others.

Stakeholder	Fuel Burn coefficient	Delay coefficient	Pollution coefficient	Capacity coefficient
Airline	1	0.5	0	0
Airport	0	1	0	0
General	1	1	1	1

Table 2 - Sets of coefficients for the tested resilience loss metrics

The non-trivial matter to adapt the well-known algorithms that solve the original formulation of the shortest path problem has been achieved in the project (corresponding to **steps *e.* and *f.*** of the approach in previous sub-paragraph), and a suitable method has been theoretically developed and implemented in a SW tool used to the project scenarios. Due to the very different kind of conditions, arising from the analysed scenarios, not all the twelve scenarios tables, as emerged from the task allocation activity, has been suitable for the methodological approach developed. The methodology, anyway, has been applied to many scenarios. Finally, the whole approach to Resilience Engineering of the ATM as an optimal task allocation problem has been finalized in the project. No inconsistencies have been found in the approach application to several scenarios which have been used as study cases in the project.

For the final ***step g.,*** a dynamic simulation environment for testing the physical feasibility of the approach has been purposely developed and applied to the selected scenarios, showing the whole consistency of the solutions.

A potential limitation of the flow solutions above discussed is, in fact, that they do not take into account time explicitly. As said, these solutions are a list of actions and tasks to be performed by the actors of the scenario. The execution of the solution flow "as is" within a real-time world, may either preserve the feasibility of the scenario or it may alter significantly the scenario. In general aircraft manoeuvres, collaborative decision making, human behaviour, system computations, data transmissions, clearances, procedures, etc. take a finite amount of time to be completed. If any of these interactions are tightly coupled (in the sense that they do not tolerate delay) then bad timing could possibly disrupt the feasibility of the optimal solution meaning that the optimal task flow is incompatible with the physical evolution of the scenario (weak emergence). Time-based simulations will address weak emergence in the sense that they will address the feasibility of the solutions found using the SAFECORAM approach. In fact "unfeasibility" as such can be viewed as an emergent behaviour that, in turn, can give better insight to the overall analysis of the scenarios and of the optimization methodology.

In SAFECORAM the modelling approach that appears more suitable to capture the general characteristics of the ATM system is the Agent-Based (AB) simulation methodology. In fact in AB simulation, the modeller defines the behaviour only at the actor level, while the global behaviour emerges as the result of many individuals, each following its own behaviour rules, moving in some environment and communicating with each other and with the environment. In the SAFECORAM project, the AB model simulates the ATM system at mesoscale level with a medium level of abstraction. The overall goal of the simulations is either to validate the optimal task reallocation strategy or to output a set of recommendations to be considered in order to improve the scenario analysis or the optimization methodology. Feasibility will be checked against loss of separation (w.r.t. other planes or terrain), excessive delay, excessive fuel consumption.

Summarising the initial idea, which fed the project development and, by collecting the achieved results, it is possible to state that:

- the ATM system resilience, for the year 2050 and beyond, could become a relevant issue with which to deal, due to the complexity, dimension and automation level of the system as expected for the long term future;
- high level of automation are expected for the future of the ATM system, in which the human preserves a central role, but it will change from an operative role to a management role and finally to an observer role, claimed to intervene just in case of emergency;
- in order to improve the resilience of the ATM system, sharing the authority for the system functions execution between residual resources is resulted as a viable approach;
- The proposed sharing of authority approach allows to allocate to the best performing actor, either human or machine, in a non-nominal conditions arising from a "disturbance" affecting the ATM system, the functions which assure the whole ATM system performance could be degraded of the lowest possible level.

As far as the most relevant future activities is concerned for the actual applicability of the proposed approach, it has to be minded that the proposed approach relies on two critical elements: a task allocation method and the performance framework assumed for the ATM system. On both those aspects, many activities are on-going. Several research projects, as found in the scientific literature, aim to propose a task allocation model: at this stage, it seems there are no one of those models which embeds a quantitative link with the ATM performance measure.

On the other critical aspect, although steps have been done in the definition of the SESAR Performance Framework, its quantitative completion is still to be expected.

The completion of the SESAR Performance Framework and the development of a task analysis and a task allocation method, quantitatively connected to that performance framework, are the more challenging advancements to be achieved for the factual applicability of the proposed resilience engineering approach.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- summarise the technical contents and results of the project (see ‘Publishable Summary’);
- provide a complete overview of all deliverables;
- provide a complete overview of all dissemination activities (past and in progress);
- describe exploitation possibilities;
- provide a complete overview of the billing status, eligible costs, planned and actual effort (including an explanation of the discrepancies);
- analyse the lessons learnt at project level.

1.2 Intended readership

This report is written for the professional reader and assumes an understanding of air transport and ATM. It provides a summary of a project focused on the development of an original approach to resilience engineering in ATM. Other researcher and SESAR WP_E responsible are the relevant intended readership of the document, hoping the document can foster an exchange of ideas and suggestions for the further analysis and development of the main achievements and issues that the project allow to identify.

1.3 Inputs from other projects

Not applicable.

1.4 Glossary of terms

Not applicable.

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D1.1	**Automation level baseline assumption for the definition of ATM scenarios.**	This Deliverable details the results, to date, of the literature review, scopes the available data for the project, and presents the initial design of the POEM model. It also scopes the model data requirements and begins the metric design with reference to the literature review and the model plans. (44 pages)	Approved
D1.2	**Study Reference Scenarios**	Twelve reference scenarios, which will be used in the study for the development, application and evaluation of the methodology under development, have been defined. Scenarios description also contains the relevant failure or emergency occurrence to be considered, which effects are in some case local, limited to a very limited area, in some other cases, they extend in a wide geographical region. For each scenario, relevant actors have been identified, and, as a consequence of the failure occurrence, the possible alternative behaviours of each actors, depicted.	Approved
D2.1	**Failures Emergency Scenarios**	A modelling approach of task allocation for Emergency/Failure conditions is proposed. The rationale for the architecture of the model is provided, based on one hand, on the overview of the state of the art of the performance methods in literature, and on the other hand, on the identification of the need for implementing of a model using quantitative values for the performance metrics.	Approved
D2.2	**ATM actors performance identification in failure/emergency scenarios**	The document describes the ATM actors performance identification in failure/emergency scenarios proposed in the SAFECORAM project. The quantitative modelling approach, as defined in D2.1, is here applied to the analysis of the twelve scenarios described in D1.2, in order to quantify the performance levels of involved actors in managing the non-nominal conditions of those scenarios. The report will contain, in a tabular fashion, the results of such modelling approach by identifying the possible task allocation to the involved actors, and the measures of expected quantitative indicators in performing those tasks.	Approved
D3.1	**Preliminary Study on Methodology**	The document approaches the state-of-the-Art and analysis of methodological approaches to optimal path recognition to be applied to resilience optimization. As a preliminary study about the methodology for resilience management problem in ATM systems, this document identifies the key aspects that should be taken into account in the formal definition of the problem. The document provides an overview of the different definitions of resilience and a state-of-the-art review of the applications of resilience paradigm in several domains. Within each domain, resilience concept and its basic attributes are described. Furthermore, the document reports a survey of the metrics that have been introduced for a quantitative measurement of resilience. Finally, the document introduces the definition of a resilience metric for an ATM system and formally states the resilience management problem as an optimization problem.	Approved

D3.2	**Methodological Approach and Demonstrations Report**	The proposed methodology for the resilience engineering has been implemented in applicable SW tools. The application of the methodology to the project scenarios has been done. Several different performance indices have been defined, on the base of the suggestions collected from the Operational Experts, and utilized in order to highlight how different solutions could be found in relation with those various performance indices. Specific situations which can prevent the tools applications and the possible improvements to be implemented have been identified and discussed.	Approved
D4.1	**Models and Scenarios SW Implementation**	Starting from the actors identification (D1.1) and task allocation analysis (D2.2), a detailed survey of bibliographic references and existing simulation models has been carried out in order to identify the most convenient approach to the modelling and time simulation behaviours of the different actors composing the project scenarios. While the documentation to define simplified models of the actors is available, the implementation at the right description level and the build of a simulation environment able to manage the different models resulted more time demanding than expected. The resulting modelling and simulation approach for each of the actors identified is the aim of the document.	Approved
D4.2	**Validation Report**	The report will describe the results of the dynamic simulation on the scenarios which have been processed by the developed methodology for resilience engineering. The dynamic models proposed for any of the involved actors, as described in D4.1, will be implemented in a suitable software environment and the specific simulation will be carried out. The software environment developed for each of the scenarios, either nominal or under disturbance, and the results of the dynamic simulations will be documented in the Validation Report.	Under Approval

Table 3 - List of Project Deliverables

3 Dissemination Activities

The dissemination activities of the original approach proposed in the project to the resilience engineering problem in ATM started with the participation to the SIDs for the years covered by the project, both in the form of participation to the poster session and in the full-paper presentation sessions.

Other relevant context - namely AIAA_ATIO Conferences, ComplexWord and ATACCS Workshops - have been also considered, and an active attendee to those context has also been assured.

Papers presented at some of the mentioned Conferences have been accepted for publication on Journals, as in the here under tables specified.

3.1 Presentations/publications at ATM conferences/workshops/journals

Event	Location and date	Title of presentation	Description
Third SESAR Innovation Days	KTH Royal Institute of Technology, Stockholm (26-28 NOV 2013)	***Sharing Of Authority In Failure/Emergency Condition For Resilience Of Air Traffic Management***	Poster Session Presentation. The SAFECORAM basic structure and, above all, base concept is described. The definition for Resilience engineering as expected to be used in the project is introduced and discussed. Examples of scenarios to be used in the project are provided.
ComplexWorld (SESAR WP-E Network) workshop	Toulouse (10 July 2013) (run in parallel to the ATOS/ISIATM Conf. 2013)	***Resilience and robustness in ATM***	The detailed vision for Resilience definition is provided, highlighting the different view for robustness and resilience as interpreted in SAFECORAM. Similarities and Differences with the definitions and approach used in Resilience2050 has been discussed.
Fourth SESAR Innovation Days	Univ. of Madrid, Madrid, (25-27 NOV 2014)	***Scenarios design and analysis approach of non-nominal conditions for resilience engineering in ATM***	Poster Session Presentation. The 12 scenarios used in the project development are described in details. The focus of the presentation is put on the description of a task allocation method which allow a quantitative performance measure of the task. The SESAR Performance Framework is used as reference framework for performance measures.
Fourth SESAR Innovation Days	Univ. of Madrid, Madrid, (25-27 NOV 2014)	***Resilience management problem in ATM systems as a shortest path problem***	The Resilience Engineering concept, as intended in many different research areas is presented and, based on definitions used in relevant context for the project (EUROCONTROL), the way to approach Resilience Engineering in ATM is proposed. Based on the defined vision, the resilience engineering approach is solved as a short path problem and method to support the approach are identified.
15th AIAA Aviation Technology, Integration, and Operations Conference	Dallas, TEXAS, USA, 22-26 June 2015	***Modeling Approach for Resilience Engineering of the Future ATM System***	The modelling of ATM system most suitable for the validation of the Resilience Engineering concept as proposed in the SAFECORAM project is presented. Different actors of the ATM system relevant to the proposed approach are described and respective modelling approach is presented.
5th International Conference on ATACCS	University Paul Sabatier (IRIT), Toulouse, France — September 30 — October 2, 2015	***Performance-based Optimization for Resilience Engineering in ATM***	Poster Session Presentation. The poster presented at ATACCS2015 focuses on the quantitative approach of the proposed task allocation method which can support the interpretation of the ATM resilience engineering problem as an optimization problem based on the SESAR performance framework.
Fifth SESAR	Università di Bologna,	***Application and***	Poster Session Presentation.

Innovation Days	Italy. 1st – 3rd December 2015	***Validation of the SAFECORAM Approach to Resilience Engineering in ATM***	The whole SAFECORAM definition, approach and results are condensed in the presentation. The relevant project aspects are discussed, focus being concentrated on the results of methodological approach application to relevant project scenarios. The validation approach to the results is introduced.
Elesvier Journal on Air Traffic Management – SIDs Special Issue		***Resilience management problem in ATM systems as a shortest path problem***	A revised, extended version of the full paper presented at SID2014 has been submitted for Journal publication, under invitation. Issues roughly described in the conference paper are detailed and, above all, case studies with results of methodological approach application are discussed.

3.2 Presentations/publications at other conferences/journals

Event	Location and date	Title of presentation	Description (and feedback)
2nd Workshop on Cyber Security and Resilience of Large-Scale Systems	Univ.of Guimaraes, Portugal (07-09 Oct. 2015)	***An Analytical Approach for Optimal Resilience Management in Future ATM Systems***	The paper presented in a context better suited to informatics and data management topics, addresses mainly the aspects aiming to present the ATM system as a complex system of systems, the interpretation of resilience for such a system, the proposed performance framework for such a system, and the proposed approach to manage the resilience for the ATM system. The paper has been included in the Book of Proceedings of the Conference, published by Springer.
AIAA Modelling and Simulation Technologies Conference	San Diego, California- 4-8 January 2016	***Simulation Approach to the Resilience Engineering Assessment of the ATM System in Crisis Scenarios***	The modelling approach of the whole ATM system and the simulation environment built in order to support the dynamic validation of the optimal solutions to the resilience engineering problem, as derived for the project scenarios used as case studies.
AIAA Journal		***Modeling Approach for Resilience Engineering of the Future ATM System***	The AIAA paper has been selected for publication on the AIAA Journal of Air Transportation. The paper will be extended to the deepen discussion of the case studies and on the way the dynamic simulation can improve the validation of the optimal resilience engineering in ATM problem.

3.3 Demonstrations

Not applicable.

3.4 Exploitation plans

The project outcomes, beyond the original global proposed approach to improve the ATM system resilience by means of a re-allocation of tasks between human and machines resources, still available after the system-disrupting event, can be identified essentially in the following items:

- The optimal search path tool, that is the tool for the analysis of a complex graph, as that representing the whole complex ATM system as a state machine collecting all the possible actors of the system and their respective tasks;
- The simulation tool for the analysis of the dynamic behaviour of the whole ATM system.

The ATM system simulation is expected to be used in several future activities. The simulation tool has been built as a modular library, which can allow to build a variety of different ATM scenarios in a very quick way. Both humans and automatic systems are included in the library, and they can be simply composed in new complex schemes representing different specific real scenarios. Also if human physical behaviour are currently simulated by simple dynamic systems (pure delay, filters, etc.), the modular approach used will allow to change (and improve) single component with no change to global environment.

The dynamic simulation library and tool will be commonly used in future activities, as a basic support tool for the system performance evaluation.

In fact, together with the wide typology of ATM system actors included in the library, the development of the tool as part of the SAFECORAM project also suggested to add to each component of the simulation library the computation of the corresponding performance indices, as defined inside the project.

Currently, just four different indices have been identified as quantitatively measurable, and consequently those only indices have been associated to each model simulation library. Anyway, as SESAR performance framework progresses in defining new quantitative indices, improvements could be done to the dynamic models, in order to allow quantitative performance evaluation of ATM scenarios.

Finally, it is expected an extensive possible use of the dynamic simulation environment developed inside the SAFECORAM project, also in supporting the performance evaluation of specific ATM scenarios.

Improvements to this first tool are expected in the humans (pilot, remote operator, ATCo, managers, etc.) tasks execution simulation, for which very simplified models have been implemented in the current release of the tool, and to the implementation of new performance metrics and indices, as they will be defined in the SESAR ATM Performance Framework.

Also the optimum search path tool could be widely exploited in a wide range of applications. The tool, which basically implements the Dijkstra method for the shortest path problem, has been implemented in an easy-to-use way. The quantitative task allocation are directly read from an Excel table, in which actors associated tasks are listed together with corresponding performance weights. The tool automatically builds a graph, also highly extended graph, and the best performing path is found.

The method can easily be applied to different global performance indices, differently computed, and it is not dependent on the number of actors and tasks each actor can perform. Due to its flexibility and scalability, the method, and the implementing tool, can be used in selecting the best task allocation in a variety of vary different conditions, and can be used to identify the “best” solution in a variety of situation: minimum global delay flights arrangements, minimum fuel burn and noise emissions conditions, and so on.

Characterization of the tool could be easily configured for single stakeholder interest and views.

Improvements to the tools are also required for a more extensive applicability. Iterative cyclic structure of task allocation are not correctly analysed by the current tool, also if this situation emerged in the project scenarios analysis performed.

The exploitation of the proposed approach as a whole will require the development of a well assessed task allocation method, which is beyond the scope and the dimension of the project: many efforts in the ATM research context are currently underway, such as the development of the FRAM environment demonstrate: actually, not quantitative proposal for task allocation method have been found in the literature analysis.

It is desirable that the proposed approach in the SAFECORAM project, which suggest and make some steps in the direction of create a link between proposed task allocation approach and the SESAR Performance Framework could be further improved in the future.

This is probably the most complex and desirable possible exploitation of the SAFECORAM outcomes.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
11DEC14	D0.1; D0.2; D5.1; D1.1;	€27959,81		Paid
11DEC14	D0.3; D0.4; D1.2; D2.1;	€62567,33	€1210,98 (travel);	Paid
22DEC14	D0.5; D0.6; D2.2; D3.1; D5.2	€72153.90	€2040,00 (travel)	Paid
09/12/2015	D0.7; D0.9;D3.2; D4.1;	€75823.20		Paid
JAN2016	D0.10; D4.2; D5.2	€35542,10 (TBC)		Pending
GRAND TOTAL		€274064.34 (TBC)	€3250.98 (TBC)	

Table 4 - Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
CIRA (GRAN TOTAL)	526 *(as 7.5 hours/day)*	520	€378704.33	€274064.34	

Table 5 - Overview of Effort and Costs

5 Project Lessons Learnt

5.1 Management aspects

What worked well?
The project achieved all the expected outcomes, essentially in-line with estimated budget, resources and time schedule.
The project allowed to integrate different expertise, many of which not used to manage the Air Traffic Management topics and issues, around a common problem, approached from different point of view. The positive result of the experience has been favoured because it was totally developed by a single entity, CIRA, but the matured experience is generally exploitable.
The project has been supported by Operational Experts, which is not a common experience of the project participants. It is hopefully, this could allow to improve the project validity, the project adherence to realistic scenarios, the use of more adherent language in describing problem and issues, the project results improved understanding by different stakeholders.
The presence of a dedicated Project Officer, supportive on both technical and management aspects, assured to address correctly from the beginning some possible project weak points and to maintain at low level the administrative burden.
What should be improved?
The cooperation and information exchange with other WP_E project could be improved. The SJU management of WP_E encourage this kind of relations, but this is a time and resources spending activity. A better evaluation of the man/power, which resulted adequate just for carrying out project activities, to be dedicated specifically to this task, is required.
The involvement of Operational Experts has been initially not correctly managed, being the experts invited to evaluate already designed scenarios and approach, while a more proactive involvements in defining scenarios – as done in a subsequent project phase – revealed more fruitful.

Table 6 - Project Lessons Learnt – Management Aspects

5.2 Technical aspects

What worked well?
The definition of the ATM system overall scenario for long term future required an extensive analysis of available documentation on tendencies, expected improvements, technical enablers as identified by major ATM agencies agendas. This analysis allowed to build a considerable background of primary aspects of the future ATM system, its complexity, its actors and their role, its major future issues.
An operative definition of Resilience Engineering in ATM has been developed in the project. References to “qualitative” definition of Resilience has been considered - first of all the definition assumed by EUROCONTROL and derived from Hollnagel original definition. Moreover, thanks to comparisons and discussions held with other project and groups working on the matter (ComplexWorld, Resilience2050), a definition compatible with the other ones and that could be practically “translated” in a quantitative measurable index has been finally assumed.
The quantitative global resilience metric has been referred to the SESAR Performance Framework. The SESAR performance framework is currently under development, and some quantitative indices for a few key performance areas has been defined. The effects of degradation in KPIs (loss of performance of the ATM system) has been used to produce a quantitative measure of the ATM system resilience. Being the way to measure the performance degradation a key issue in all the resilience metric definition, the proposed way to link the resilience measure to the SESAR performance Framework definition is considered an original proposal

to be taken into account in future works.
A preliminary task allocation model which has a quantitative relation to the ATM system performance has been proposed. Other task allocation model have been taken from the literature; because it has been recognized the need for a quantitative capacity to measure the performance of the system related to the allocation of each task, a proposal for the quantitative improvement of the method has been operatively proposed.
Twelve different scenarios, exploring a wide variety of disputing conditions, from FMS degraded performances to closure of airspaces, have been developed in order to analyse applicability and scalability of the procedure.
The capacity to build a methodology which implements the basic project idea of manage the ATM system resilience as a task re-allocation between the system resources (both humans and machines) still available after the disrupting event that degrade the ATM performance.
The efficient implementation of the proposed methodology, which used common (and possibly) open software to implement the methodology for the search of best the task allocation, among all the possible ones, which best assures to preserve the highest ATM system performance level (optimisation of system resilience).
The development of a library for the dynamic simulation of ATM scenarios. All the relevant actors of the ATM system have been identified and their relevant behaviour described in terms of dynamic models. All the dynamic models so defined have been implemented in a suitable SW environment for an user-friendly construction of ATM scenarios to be simulated, both in fast and in real-time.
What should be improved?
The SESAR Performance Framework has currently very few quantitative KPIs. As the SESAR Performance Framework will progress, new more complete definition of resilience metrics have to be assumed.
The quantitative task allocation method proposed is largely "preliminary". Many methods have been considered, no one having a direct quantitative relation with a possible performance index. Due to also the initial state of the SESAR performance Framework, just a possible first proposal for such a method has been defined in the project, in order to demonstrate the global proposal feasibility.
Due to the lack of data and exhaustiveness of performance reference framework, a number of assumption, mainly based on the developers' experience, have been done in defining the relation between task allocation and performance degradation.
In some case, the actors tasks in non nominal conditions do not allow an easy definition of task re-allocation. This weakness in some scenario definition emerged only as inapplicability of the methodology. A guideline for the definition of the scenarios can be developed, in order to support a clear task allocation.
The implementation of the "minimum path search" method to the resilience problem could still be improved in some aspects, as in providing an easy way to identify and interpret the best task allocation solution found as resilience problem solution.
At the moment, the best task allocation solution and the dynamic feasibility of that solution are analysed as distinguished consequent steps of the procedure. Also if this approach does not compromise the validity of the solution, the dynamic simulation tools could be integrated in the graph analysis, in order to achieve the feasible solution in one step. Problem in integrating the two steps are currently the high computational burden required by the dynamic simulations, which can excessively extend the computation time of the optimal solution.
It is important to remark that in the SAFECORAM project it is assumed that the stochastic nature of the events that can affect the scenario evolution is not taken into account. This means that the performance variability of the actors is not taken into account and therefore there are no unexpected behaviors at the actors level. The stochastic nature of the events and behavior can widely enlarge the approach applicability (and complexity).

Table 7 - Project Lessons Learnt – Technical Aspects

6 References

[1] A. Filippone, E02.21 PIR Part 1 SAFECORAM, July 2013

[2] Edoardo Filippone, Francesco Gargiulo, Domenico Pascarella, V. Di Vito, A. Errico, “Resilience management problem in ATM systems as a shortest path problem” SID’2014, Madrid Spain – Nov. 2014.

[3] Edoardo Filippone, V. Di Vito, A. Errico, G. Torrano, P. Caruso, G. Cuciniello, “Scenarios design and analysis approach of non-nominal conditions for resilience engineering in ATM”, SID’2014 Poster Session, Madrid Spain – Nov. 2014.

[4] Edoardo Filippone, Roberto Palumbo, Francesco Gargiulo, Domenico Pascarella, “Application and Validation of Resilience Engineering Approach in ATM - Application of an optimal task re-allocation and its validation through dynamic modelling of the ATM system in support of the SAFECORAM approach to resilience engineering in ATM”, SID’2015, Poster Session, Bologna, Italy – Dec. 2015.